Emission Control

Hurricane & ReCyclone® Systems
Advanced Cyclone Systems

A company exclusively dedicated to the development of optimized cyclones

VISION  Leading the conception and distribution of cyclone systems on a global level, contributing to a healthier environment and to the growth of client’s competitiveness, maintaining high standards of service and quality with qualified and motivated human resources.

MISSION  Maximizing particle capture with cyclones, freeing the client from the costs and problems of bag filters.
ACS has grown to become a worldwide reference in cyclones in 8 years of existence

- Established in May 2008 by Pedro Araújo and Romualdo Salcedo, supported by the CoHitec program and promoted by COTEC
- Backed by Espírito Santo Ventures in 2009
- Headquarters in Porto, Portugal, with 18 employees today
- Unique scientific knowledge in cyclone design optimization and particle agglomeration modeling (PACyc) in partnership with the Engineering Faculty of Porto (FEUP) where it runs a pilot system for R&D.
- Has become a worldwide reference in cyclones, with over 200 successful installations in 30 countries in 8 years
- Scalable, profitable business model based on:
  - Clearly differentiated market position
  - Optimized cyclone design and accurate efficiency prediction capabilities
  - Validated right first time installation
  - Introducing standardized solutions to meet a wide range of client industry applications
Advanced Cyclone Systems

Provider of high performance gas/solid separation at a lower total cost of ownership

By its superior efficiency, ACS cyclones displace other more maintenance demanding technologies, such as Bag Filters, or much more expensive ones, such as ESPs
Proven technology, global footprint ACS has installed products in 30 countries

Number of installations per country

North, Central & South America  Europe  Africa  Asia  Oceania
Filtration and Separation technologies

Two main market needs

**EC**
**EMISSION CONTROL**
Environmental Improvement

- Increasingly strict Particulate Matter (PM) emission limits are being enforced worldwide. Poor air quality is the **number 1 environmental cause** of premature death in the EU*

- Majority of combustion processes are associated with PM Emissions. Cleaning hot gases is mandatory for **heat recovery** and to improve plant efficiency.

- Many other processes in large industrial plants are sources of PM: (Steel, Cement, Paper, Glass... etc.).

**PR**
**POWDER RECOVERY**
Serious Economic Added Value

- **60% of the world chemical related industries** handle products in the fine powder form.

- Significant shares also apply to the **Pharmaceutical Food Ingredients, and Mineral industries**, among others.

- Virtually all powder processing industries need gas-solid separation

- Many are actively seeking to optimize the yield of their processes and reduce powder losses.
HOW CAN ACS TECHNOLOGY SOLVE EMISSION PROBLEMS?
Despite numerous advantages, regular cyclones have low efficiency

Reverse flow cyclones benefits:

- Robust
- Absence of maintenance
- No pressure problems
- No moving parts
- Work on a dry basis
- No temperature restrictions
- No electrostatic components
- No filters

Wide Industrial Application

**Problem:** Low efficiency for particles < 10µm*

*1µm = 1/1000mm

Typically, traditional “non optimized” cyclones have to be complemented with other separators due to their low efficiency
Example of different types and sizes of cyclones
Alternative technologies for emission control have operational and cost drawbacks

**Sources & Problems**

**Usual sources of PM emissions:**
- **COMBUSTION PROCESSES**
  - Boilers, Furnaces, Incinerators, Gasifiers
  - **Biomass Boilers**
    - District water heating
    - Heat production in industry
    - Steam production in industry
  - **Pellet manufacturing**
- **DRYING PROCESSES**
  - Rotary Dryers, Vertical Dryers
  - **Biomass Dryers**
    - Pellet manufacturing
    - Particle board manufacturing

**Problems of existing solutions:**
- **Bag Filters**
  - Critical operational problems & high maintenance costs at high temperature or moisture.
- **Electrofilters (ESP's)**
  - High investment cost & restricted applicability
- **Wet Venturi Scubbers**
  - High operational costs and production of secondary wet pollution with associated treatment costs.

**Need for an affordable, efficient and problem free technology!**
THE SOLUTION:
NEW & MORE EFFECTIVE CYCLONES!
## The solution: much more efficient cyclones

How do we improve cyclone efficiency?

<table>
<thead>
<tr>
<th>01</th>
<th>Understanding How Cyclones Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Difficult to model cyclone separation dynamics</strong></td>
</tr>
<tr>
<td></td>
<td>Cyclones are usually designed empirically or, less often, according to models which can be found in the literature that do not consider the inter-particle agglomeration inside the cyclone</td>
</tr>
<tr>
<td></td>
<td><strong>ACS has developed its own unique model for cyclone efficiency prediction which takes into account agglomeration (clustering) in turbulent flow fields</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>02</th>
<th>Optimizing Cyclone Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACS can rapidly generate millions of virtual prototypes and, through numerical optimization, select the best geometry to each given cyclone application</td>
</tr>
<tr>
<td></td>
<td>This takes into consideration several economical and operational constraints, such as size, pressure loss or manufacturing cost.</td>
</tr>
<tr>
<td></td>
<td><strong>The optimization approach has resulted in multiple cyclone patents</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>03</th>
<th>Unique Cyclonic Recirculation Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACS has further increased cyclone efficiency with unique patented recirculation systems, using pure mechanical or electrostatic dynamics (ReCyclone®)</td>
</tr>
</tbody>
</table>

ACS' competitive advantage is sustained by its unique ability to accurately estimate, and consequently guarantee a requested efficiency, resulting in better cyclones optimized for a specific application.
Understanding how cyclones work
Developing the best theory for cyclone collection

Predicting particle agglomeration in cyclones (PACyc)

Trajectories
Agglomerate Formation
Optimizing cyclone efficiency

Designing the best cyclone system for each application

2 level factorial experiment → 128 prototypes
4 level factorial experiment → 16384 prototypes

Numerical optimization

Able to generate millions of “prototypes”

Empirical development

8 dimensions
4 axial
4 radial

Cleaned gas
Dusty gas
Dust

4/17/2018

www.acsystems.pt
Optimizing cyclone efficiency

Designing the best cyclone system for each application

Thanks to the PACyc Model it is possible to simulate millions of virtual prototypes resorting to numerical optimization.

Different industrial cases have different needs for which the optimization functions to incorporate in the PACyc model may be as complex as minimizing cost or space, subject to a minimum efficiency result.

The cyclone families above are the result of very different client demands ACS has come across until now.
Optimizing cyclone efficiency
Designing the best cyclone system for each application

Alternative Cyclone Solutions – Real Case Analysis: Biomass Boiler Dedusting

Operating Conditions: 4MWth, wood chips moving grate boiler

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Wood Chips</th>
<th>Gas Temperature</th>
<th>Flow Rate</th>
<th>Moisture Content in the Flue Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSD Median (Volume Based)</td>
<td>11µm</td>
<td>180ºC</td>
<td>356ºF</td>
<td>18000m³/h</td>
</tr>
<tr>
<td>Inlet Concentration</td>
<td>750mg/Nm³</td>
<td>18000m³/h</td>
<td>10594 ACFM</td>
<td>8% (v/v)</td>
</tr>
</tbody>
</table>

Global Efficiency (%):

- **MK**: 96%
- **EX**: 95%
- **RE**: 92%
- **RX**: 87%
- **HR**: 82%
- **TX**: 74%
- **AT**: 61%
- **DX**: 52%
- **SD**: 39%

Emissions (mg/Nm³):

- **SO₂**: <29
- **NOₓ**: <38
- **CO**: <60
- **O₂**: <96
- **O₃**: <132
- **NH₃**: <196
- **H₂S**: <270
- **CO₂**: <357
- **CH₄**: <458

4/17/2018
www.acsystems.pt
# Optimizing cyclone efficiency

Designing the best cyclone system for each application

<table>
<thead>
<tr>
<th>Cyclones needed (φ1000mm):</th>
<th>System size:</th>
<th>Objectives / Applications:</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK</td>
<td>100%</td>
<td>The agglomerator cyclone – Maximum agglomeration. Most efficient cyclones available on the market.</td>
</tr>
<tr>
<td>EX</td>
<td>65%</td>
<td>Ultra high efficiency with agglomeration to compete with ESPs.</td>
</tr>
<tr>
<td>RE</td>
<td>53%</td>
<td>Very high efficiency cyclone with agglomeration for strict emission limits.</td>
</tr>
<tr>
<td>RX</td>
<td>33%</td>
<td>Final stage dedusting for stricter emission limits.</td>
</tr>
<tr>
<td>HR</td>
<td>23%</td>
<td>Compact high efficiency cyclones for multiple applications. Half the emissions of Multi-cyclones.</td>
</tr>
<tr>
<td>TX</td>
<td>15%</td>
<td>Final stage dedusting for moderate emission limits. Better performance than multi-cyclones.</td>
</tr>
<tr>
<td>AT</td>
<td>10%</td>
<td>Enhanced Pre-Separation. Sparks &amp; silica reduction upstream of dryers.</td>
</tr>
<tr>
<td>DX</td>
<td>7%</td>
<td>Improved Pre-Separation for coarse and medium particle size. Alternative to axial multi-cyclones.</td>
</tr>
<tr>
<td>SD</td>
<td>6%</td>
<td>Coarse particle scavenging. Ammonia reduction, better efficiency over DEAC.</td>
</tr>
</tbody>
</table>

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ACS' cyclone designs substantially decrease global emissions

Residual emissions comparison between ACS products

<table>
<thead>
<tr>
<th>Design</th>
<th>Residual Emissions (mg/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane</td>
<td>10</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>21</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>29</td>
</tr>
<tr>
<td>Hurricane</td>
<td>12</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>30</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>38</td>
</tr>
<tr>
<td>Hurricane</td>
<td>10</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>45</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>50</td>
</tr>
<tr>
<td>Hurricane</td>
<td>19</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>60</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>60</td>
</tr>
<tr>
<td>Hurricane</td>
<td>29</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>67</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>76</td>
</tr>
<tr>
<td>Hurricane</td>
<td>96</td>
</tr>
<tr>
<td>Recycle MH</td>
<td>132</td>
</tr>
<tr>
<td>Recy. EH</td>
<td>132</td>
</tr>
</tbody>
</table>

Residual emissions (mg/Nm³) at the stack from slide 17. **Example: 4MWₚₜ, biomass boiler**

Designing the best cyclone for the client
Selecting between mechanical or electrostatic recirculation to decrease global emissions in 50 or 75%, respectively
Adding unique cyclonic recirculation systems

See Hurricane & ReCyclone in 3D action

Click here for 3D animation
ACS’ cyclone designs substantially decrease global emissions

Efficiency comparison between ACS alternatives, a Bag Filter and a competitor cyclone.

Quimigal | Portugal | 2009
ReCyclone EH
to recover sulphanilic acid

Global efficiency:
- Bag Filter 99.0%
- Competitor HE cyclone 95.0%
- Hurricane 98.5%
- ReCyclone® MH 99.6%
- ReCyclone® EH 99.8%
Systems are generally supplied in pre-assembled modules for easier installation

ACS systems are mostly supplied in groups of cyclones (batteries) and recirculators, disposed vertically instead of horizontally, to minimize layout space. Usually, supply includes the support structure, insulation, ductwork, recirculation fan and control board.
HOW WE COMPARE WITH OTHER TECHNOLOGIES
ACS Cyclones are optimum for emissions control

Residual emissions comparison between ACS products

<table>
<thead>
<tr>
<th>Technology comparison for wood chip combustion</th>
<th>Multicyclones</th>
<th>Wet Venturi Scrubbers</th>
<th>Bag filters</th>
<th>ESP’s</th>
<th>Hurricane systems</th>
<th>ReCyclone® MH systems</th>
<th>ReCyclone® EH systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (%)</td>
<td>50 to 80</td>
<td>89 to 93</td>
<td>98-99 +</td>
<td>95 to 99</td>
<td>82 to 96</td>
<td>87 to 97</td>
<td>94 to 99</td>
</tr>
<tr>
<td>Emissions: (depending on Hurricane collector)</td>
<td>&gt; 150</td>
<td>49 to 70</td>
<td>&lt; 20</td>
<td>5 to 35</td>
<td>29 to 132</td>
<td>21 to 97</td>
<td>10 to 44</td>
</tr>
<tr>
<td>Temperature limitations (°C)</td>
<td>No</td>
<td>No</td>
<td>&lt; 250</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>&lt;400</td>
</tr>
<tr>
<td>Fire risk</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Resistivity sensitivity?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>High</td>
<td>No</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>Pre-separation needed?</td>
<td>No</td>
<td>No</td>
<td>Always</td>
<td>Frequently</td>
<td>Unfrequent</td>
<td>Unfrequent</td>
<td>Unfrequent</td>
</tr>
<tr>
<td>Consequences of electrical field failure</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Plant shut down</td>
<td>None</td>
<td>None</td>
<td>Works mechanically</td>
</tr>
<tr>
<td>Moving/replacement parts</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Relative investment costs</td>
<td>20/100</td>
<td>(45 to 55)/100</td>
<td>60/100</td>
<td>100/100</td>
<td>(35 to 55)/100</td>
<td>(45 to 65)/100</td>
<td>(60 to 70)/100</td>
</tr>
<tr>
<td>Relative operating costs (Energy and Maint.)</td>
<td>4/100</td>
<td>20/100</td>
<td>10/100</td>
<td>4/100</td>
<td>6/100</td>
<td>10/100</td>
<td></td>
</tr>
<tr>
<td>Future retrofitting costs</td>
<td>Very low</td>
<td>Low</td>
<td>Very high</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
<td>Very low</td>
</tr>
<tr>
<td>Downtime costs</td>
<td>Very low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Comments</td>
<td>Dry-System</td>
<td>Sec. Pollution Needs Treatment</td>
<td>Dry-System</td>
<td>Dry-System</td>
<td>Dry-System</td>
<td>Dry-System</td>
<td>Dry-System</td>
</tr>
</tbody>
</table>

Indicated values are from page 5. Example: 4MW<sub>b</sub> biomass boiler. Range of emissions figures depend on the type of cyclone family used.
Hurricane AT

to reduce sinter dust at high temperature to avoid production downtime due to fan part replacement in consequence of abrasion.

- **Technology**
  Hurricane AT

- **Application**
  Reduce sinter dust at high temperature to avoid production downtime due to fan part replacement in consequence of abrasion.

- **Dimension**
  651 864 m³/h at 350ºC
  383 673ACFM at 662ºF

- **Guaranteed Emissions**
  <100 mg/Nm³ dry
  <0.12 lbs/MMBTU

- **Alternative technology**
  Other cyclones from alternative manufacturers, more expensive for the same efficiency
Glowood | Portugal | 2014

Hurricane HR
PM emission reduction after dryer cyclones of rotary dryer

- **Technology**
  Hurricane HR

- **Application**
  PM emission control in

- **Dimension**
  71 839m³/h at 87°C
  42 283CFM at 189°F

- **Load into Cyclone System**
  ≈700mg/Nm³ dry
  ≈0.84lbs/MMBTU

- **Guaranteed Emissions**
  <150 mg/Nm³ dry
  <0.18lbs/MMBTU
  Measured in 2015:
  12mg/Nm³ dry | 0.014lbs/MMBTU

- **Alternative technology**
  Wet Electrostatic Precipitator (WESP), 3-4 times more expensive
Hurricane HR

to reduce fly ash at high temperature in a wood waste boiler

• **Technology**
  Hurricane HR

• **Application**
  By using the biomass boiler off gases instead of natural gas for the process, the end client (Sonae Industria) saves more than 600k€ (est.) per year.

• **Dimension**
  247 000 m³/h at 305°C
  145 379ACFM at 581°F

• **Guaranteed Emissions**
  <100 mg/Nm³ dry
  <0.12 lbs/MMBTU

• **Alternative technology**
  No known alternative
Hurricane Mki

to reduce PM emissions from a biomass boiler (wood chips)

- **Technology**
  Hurricane MKi

- **Application**
  PM emission control from biomass boiler burning wood chips

- **Dimension**
  40 203m³/h at 170°C
  23 663ACFM at 338°F

- **Load into Cyclone System**
  ≈400mg/Nm³ dry
  ≈ 0.48lbs/MMBTU

- **Guaranteed Emissions**
  <65mg/Nm³ dry
  <0.078lbs/MMBTU

- **Alternative technology**
  Electrostatic Precipitator (ESP) or Bag Filter (BF)
Hurricane MK

to reduce PM emissions from a 8MWth boiler (cork dust)

- **Technology**
  Hurricane MK

- **Application**
  PM emission control in boiler burning cork dust

- **Dimension**
  22 089 m³/h at 250°C (90% load)
  13 001 ACFM at 482°F (90% load)

- **Load into Cyclone System**
  ≈1500 mg/Nm³ dry
  ≈1.8 lbs/MMBTU

- **Guaranteed Emissions**
  <100 mg/Nm³ dry
  <0.12 lbs/MMBTU

- **Alternative technology**
  Electrostatic Precipitator (ESP) or Bag Filter (BF)
ReCyclone MH

Technology
ReCyclone MH

Application
PM emission control in one biomass boiler burning wood chip

Dimension
101 206 m$^3$/h at 160ºC
59 568ACFM at 320ºF

Load into Cyclone System
≈450 mg/Nm$^3$ dry
≈0.54lbs/MMBTU

Guaranteed Emissions
<100 mg/Nm$^3$ dry
<0.12 lbs/MMBTU

Alternative technology
Electrostatic Precipitator (ESP) or Bag Filter (BF)
Recyclone EH

To reduce PM emissions from a biomass boiler flue gases

- **Technology**
  Recyclone EH

- **Application**
  PM emission control from biomass boiler (pine chips and sawdust)

- **Dimension**
  3 900m³/h at 180°C
  2 295ACFM at 356°F

- **Load into Cyclone System**
  ≈200mg/Nm³
  ≈0.24lbs/MMBTU

- **Guaranteed Emissions**
  <30 mg/Nm³
  <0.036lbs/MMBTU

- **Alternative technology**
  Electrostatic Precipitator (ESP)
PERMANENTLY INNOVATING OUR SYSTEMS
INDUSTRIAL EXAMPLES
ACS has proven applicability in a broad variety of applications

**EMISSION CONTROL**
Environmental Improvement

- Biomass and Coal Combustion
- Steel and Ferroalloys
- Pyrolysis, Incineration and Gasification
- Air Caption and Dedusting
- Biomass Dryers
- Fuel Oil Combustion
- Clinker Cooler and Pre-Heater Dedusting
- Calcination Processes
- High Temperature Separation Processes for Energy Recovery

**POWDER RECOVERY**
Serious Economic Added Value

- Pharmaceutical Ingredients
- Food Ingredients
- Mineral Processing
- Chemicals
- Nanoparticles
- Fertilizers
- Milling and Drying Processes
Filtration and Separation technologies

Two main market needs

• Cyclones are widely used in many industries

• Low cyclone efficiency results in high product losses and high emissions in many plants
  
  • Efficiency increase implies a new approach to cyclone design - PACyc

• Customized numerically optimized cyclones (Hurricane) reduce losses up to 90%

• Hurricane & ReCyclone® systems maintain cyclones’ advantages while improving efficiency dramatically, reaching near bag filter performance in several applications, while enabling thermal energy recovery.

• Wide application range with unquestionable advantages over alternative dedusters, ensuring emission limits compliance by small to medium companies

• Numerous successful case studies and environmental innovation awards